GENERAL NOAA OIL MODELING ENVIRONMENT (GNOME): A NEW SPILL TRAJECTORY MODEL

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ABSTRACT: *The General NOAA Oil Modeling Environment (GNOME) is a standard Eulerian/Lagrangian spill-trajectory model designed to meet the needs of planners and expert responders through three different user modes: Standard, GIS Output, and Diagnostic. Spills are modeled by Lagrangian Elements (LEs or splots) within continuous flow fields. GNOME supports the National Oceanic and Atmospheric Administration (NOAA)/Hazardous Materials Response Division (HAZMAT) standard for Best Guess and Minimum Regret trajectories by providing information about where the spill is most likely to go (Best Guess solution) and the uncertainty bound (Minimum Regret solution).*

The public, including spill responders, industry, and students, can use GNOME in Standard or GIS Output mode to prepare spill scenario-related products and for intuition building. These GNOME modes require a Location File that contains a regional trajectory model with a Mini-Expert System to aid in setting up the model. The Mini-Expert System sets up the trajectory model based on user input via dialog boxes. Information sources also are provided to help users answer the dialog questions.

Responders can use GNOME's Diagnostic mode to quickly set up custom trajectory models for any area, as HAZMAT does during spill response . GNOME's Diagnostic model can accept circulation patterns from any hydrodynamic model (from two-dimensional steady-state to three-dimensional time-dependent models) with proper formatting.

GNOME allows all users to save their work in files and create QuickTime movies. In GIS Output and Diagnostic modes, users can export the model results to GNOME Analyst to convert the data from LEs or splots to oil-concentration contours. Both the splots and contours can be exported to a GIS system (HAZMAT provides an ArcView extension). HAZMAT presently is creating Location Files for U.S. Coast Guard and NOAA priority locations with a design philosophy to allow users significant control over the model setup without requiring extensive spill modeling experience. GNOME, all Location Files, and documentation are available for download from NOAA's Office of Response and Restoration Web site[1] under Aids for Oil Spill Responders.

Introduction

The objective of this paper is to acquaint the reader with the General NOAA Oil Modeling Environment (GNOME)[2] and goals for future GNOME development and Location Files. GNOME is the latest spill-trajectory model developed by the Hazardous Materials Response Division (HAZMAT), Office of Response and Restoration[1], National Oceanic and Atmospheric Administration (NOAA). GNOME is a multipurpose trajectory model for use by both experts and the public via different user modes.

GNOME's Diagnostic mode is a spill response trajectory model. HAZMAT is aware that many people who are not trajectory analysts are interested in running spill trajectories for intuition building, drill scenarios, and answering "what if" questions. For these users, HAZMAT developed Location Files, which are resource files for use with GNOME in Standard or GIS Output modes. For oil spill-related planning, HAZMAT has developed a separate application—the Trajectory Analysis Planner (TAP)—to summarize thousands of individual trajectories run in GNOME.

Until the basic GNOME algorithms had been tested fully, GNOME was run jointly with HAZMAT's On-Scene Spill Model (OSSM) during all HAZMAT spill responses. The most noticeable difference between GNOME and OSSM is that GNOME has a graphic user interface (GUI, point-and-click), whereas OSSM has a command line interface. Although GNOME is now used for trajectory support, GNOME's development team has prioritized the addition of capabilities not available in OSSM, such as three-dimensional (3-D) trajectories and currents. OSSM is still used for responses that require specialized tools not yet found in GNOME, such as statistical trajectories.

Location Files contain all the necessary files an expert would use to set up a trajectory model for a particular region, with the addition of a Mini-Expert System. The Mini-Expert System consists of a short series of dialogs with questions for the user to answer and information sources that the user can find on the Internet. Location Files are not meant to be used for spill response, since they represent climatological conditions that may significantly differ from actual conditions on any particular day. Although a trajectory analysis expert may use some of the files or algorithms from a Location File during a response, the expert would adjust the GNOME model to represent conditions during the spill using GNOME's Diagnostic mode tools. A summary of the differences between the Diagnostic and Standard/GIS Output modes is given in Table 1. HAZMAT is available 24 hours a day for spill response, including providing trajectory analysis expertise; Location Files contain information on how to report spills and contact HAZMAT for spill response.

Table 1. Information flow from the user through GNOME and the available output options.

File Input Standard/GIS	Diagnostic
Location File	Length and time scale of problem
Responses to Location File dialogs	Knowledge of regional physics and uncertainty
Spill information	Map Currents (hydrodynamic models) Wind forecast (Optional) location file Spill information
Location save file (use w/ Location File)	Diagnostic save file
Quick Time movie	Quick Time movie
GIS output (MOSS format; GIS output only)	GIS output file (MOSS format)
GNOME analyst files (oil concentration contours; GIS output only)	GNOME analyst files (oil concentration contours) Color/black-and-white picture printout

Note: In Standard and GIS-Output modes, a Location File assists the user in setting up the model via a Mini-Expert System (Wizard) that converts the input into model parameters and setup. In Diagnostic Mode, the user is responsible for all model fields and parameters; thus, the user is expected to have sufficient oceanographic and spill-modeling knowledge to create and use the model appropriately.

GNOME supports the NOAA standard for trajectory output by providing both the Best Guess and Minimum Regret solutions (Galt, 1998). The Best Guess solution is the trajectory created by assuming that all model inputs are correct. The Minimum Regret solution is a statistical compilation of trajectories that samples possible forecast errors in all of the model inputs (wind, currents, horizontal mixing, etc.). This Minimum Regret spill distribution is used to create an uncertainty bound on trajectory forecasts. Because quantitative confidence limits often are unavailable for model input fields, the GNOME uncertainty bound is generally considered a 90% confidence limit based on experience. Responders can use this information to examine potential spill trajectories and evaluate the protection of highly valuable or vulnerable resources that merit response even when the probability of oil contact is low.

GNOME's trajectory model

GNOME uses the standard Eulerian/Lagrangian approach to spill modeling with the regional physics simulated as Eulerian (continuous) fields within which the oil spill's Lagrangian Elements (LEs or spill dots called splots) move. The user watches the spill evolve over time in the model as the splots move with the currents and winds. As with all trajectory models, the user must have an idea of the temporal and length scales involved to appropriately set up the model. The spilled product, amount spilled, and local dynamics will influence the persistence of the product and how far it will travel. For example, during spill response, the NOAA/HAZMAT trajectory modeling team first determines their view of the temporal and spatial scales of the response and sets up the trajectory model accordingly. GNOME is calibrated to overflight observations twice a day, and forecasts are made for up to 3 days (the temporal boundary between weather forecasts and climatology). When creating Location Files for GNOME, the development team considers the types and amounts of products that could potentially spill in the area and the regional physics that must be simulated.

GNOME is written using the latest object-oriented programming methodologies in the C++ programming language. In this way, different components of oil spill simulation and physics are all self-contained objects within the application, so they can be added, modified, or deleted as self-contained units. The physics in the trajectory simulation is broken apart into "mover" objects based on the assumption of linear superposition of mechanics that move LEs. This means that during each time step of a trajectory simulation, each LE has a known starting position and queries each active mover to find out how far and in what direction the LE would move in that time step. Then these steps are added in a vector sum to give the resulting direction and distance, and the LE is moved to the new location.

The basic movers within GNOME—currents (with and without tides), horizontal mixing, and wind—are explained below in more detail.

Currents. GNOME accepts current data output from hydrodynamic models in a number of different forms. For current patterns (2-D steady state), GNOME has separate formats for finite-element models—such as HAZMAT's CATS (Current Analysis for Trajectories) model—and for a regular rectangular-grid, finite-difference model. For 2-D and 3-D time-dependent currents, GNOME has only a custom data format, although more common public-domain formats are being investigated, such as netCDF (network Common Data Format[3]).

Current patterns can be made time dependent in several ways within GNOME. The current pattern is multiplied by a time series representing the time-dependent physics of interest, such as tides or changes in river flow rates. A tidal current time series from the nearest tide station can simulate tidal currents. The time series can either be entered as a time series of currents or the tidal harmonic coefficients. Wind-driven currents can be simulated with current patterns through GNOME's Wind Component mover. A single current pattern can be tied to a particular component of the wind time series vectors, or two patterns (generated by orthogonal wind stress directions) can be tied to two orthogonal components of the wind time series. HAZMAT uses linear current patterns when using the Wind Component mover with two patterns in Location Files.

Horizontal mixing. The oceanographic processes that spread spills horizontally are simulated in GNOME by a random walk after Csanady (1973). The user inputs a diffusion coefficient, which is used to calculate random step lengths in the x and y directions from a uniform distribution. A uniform distribution was chosen over a standard normal distribution (Apostol, 1969) because it is more conservative for estimating the extent an oil spill will spread.

Wind. Currently, wind is simulated only as a spatially constant field with optional temporal variability. Spatially variable winds are planned but have not been implemented at this time. The user may input wind data by typing, pointing-and-clicking on a wind target, or reading in a file. Wind data can be saved as a file to be used with other HAZMAT applications, such as ADIOS™ (Automated Data Inquiry for Oil Spills) oil weathering model.

Uncertainty in model/data parameters

To model the Minimum Regret solution, GNOME requires information on the amount of uncertainty associated with each *mover*. For example, the horizontal mixing estimate may be off by a factor of 2, or the currents may err by 30% in magnitude. GNOME uses these data to simultaneously run 1,000 separate, single LE spills to sample the uncertainty. Each of these Uncertainty LEs samples a different portion of the uncertainty space. One may have winds slightly faster and more to the right, a smaller diffusion, and slightly slower currents. Another might have slower winds, a much larger diffusion, and faster currents slightly to the left. The trajectories of these Uncertainty LEs map the domain for the Minimum Regret solution and are used in the GNOME Analyst application to calculate the uncertainty boundary for the trajectory.

Simulating different spills and spill products

Spill trajectory models usually combine surface physics effects caused by winds—such as wave stress, wave compression, Stokes drift (Lighthill, 1978), dispersion, over-washing, surface drift, and Langmuir circulation (Farmer and Li, 1994)—into a single model parameter called the Wind Drift Factor (Galt, 1985). GNOME's default values for the Wind Drift Factor range from 1–4%, although any values from 0–100% may be used. This allows the user to simulate subsurface tarballs or other pollutants that would be unaffected by the wind, or other objects that have greater wind effects than oil, such as drifting ships, large floating debris, or jetsam.

GNOME can simulate different spill distributions (point, line, 2-D, instantaneous, or leaking over time) through the GUI. Spill distributions can vary in space (point, line, or sprayed distributions) and in time (point and line sources simulate instantaneous spills or spills over time). GNOME uses six product types and one nonweathering type for spill simulations: gasoline, kerosene/jet fuels, diesel, fuel oil No. 4, medium crude, and fuel oil No. 6. The user interface includes spill information, simple weathering and shoreline-contact mass balance, and total mass balance when more than one spill is included. GNOME tracks the mass balance of the floating, beached, and evaporated oil, as well as any oil that has left the model domain. The evaporation algorithm in GNOME is very simple; use HAZMAT's ADIOS 2™ model for a better estimate of oil weathering.

Trajectory products

Once you have run a spill scenario in GNOME, you can create the following trajectory products (see Figure 1 for example), some of which have the option of a single frame or hourly output:

- *Printed Picture* contains spill information from the model run.
- *Save File* allows users to save their work where they left off: (.lfs) in Standard/GIS Output modes or (.sav) in Diagnostic Mode.
- *QuickTime animation* saves hourly pictures from the model run and puts them into an animation file.
- *NOAA Splot Files* display standard trajectory output for use in GIS systems.
- *GNOME Splot Files* display standard trajectory output for use in GNOME Analyst. GNOME Analyst is the HAZMAT tool for converting splot distributions into contours of relative oil concentration and an uncertainty bound.
- *Other Support Files* exported for other HAZMAT software applications include *Shoreline Map* for use in GNOME Analyst and *Wind Time Series* for use in the oil-weathering model (ADIOS™).

Location Files

Location Files are resource files for the GNOME application that contain all information pieces for the trajectory model (currents, tides, parameters) and a Mini-Expert System (the Wizard) that acts as a facilitator in helping the user customize the model setup for a specific spill/region. In this section, the author discusses the philosophy behind the Location File design, describes the user interface with Wizard and with the types of simulated physics, and gives examples of how to use Location Files. Currently, NOAA/HAZMAT is creating Location Files based on a U.S. Coast Guard priority list of 32 Marine Safety Offices (MSOs), as needed for testing GNOME development and in collaboration with other federal branches such as the Navy and State Department. Location Files that scheduled for completion by IOSC 2001 are listed below:

GNOME Location Files completed or in final stages (as of 10/15/2000):

- Apra Harbor, Guam
- Central Long Island Sound, New York, and Connecticut
- Columbia River Estuary, Oregon and Washington
- Delaware Bay, Delaware and New Jersey
- Galveston Bay, Texas
- Kanoehe Bay, Hawaii
- Mobile Bay, Alabama
- Prince William Sound, Alaska
- ROPME Sea Area (Persian Gulf)
- San Diego Bay, California
- San Juan, Puerto Rico
- Santa Barbara Channel, California
- Southeastern Mediterranean
- Tampa Bay, Florida

GNOME Location Files expected by March 2001:

- Boston, Massachusetts
- Juneau and Glacier Bay, Alaska
- Los Angeles/Long Beach, California
- Portland, Maine
- Santa Barbara Channel and Santa Maria Basin, California
- Strait of Juan de Fuca, Washington

As for any trajectory model, the first considerations in creating a Location File for a particular area are the time and length scales of the physics involved. Domains must represent the regional physics on a scale large enough to be useful and, at the same time, balance the model's limitations and the local variability. For instance, a single Location File created for the entire California coast would not be feasible because the number of questions for the user to answer would be prohibitive, and the length scale for spills over a few days could not cover such a long distance. No user would want to research and answer questions irrelevant to their area of interest (e.g., setting the Santa Barbara Channel circulation pattern makes no sense for a 24-hour spill scenario off Humboldt Bay). Spill scenarios in Standard and GIS Output modes are limited to 5 days since the Location Files capture only climatological conditions of a changing ocean.

To understand the philosophy underlying the creation of *Location Files*, consider two sets of information (see Figure 2):

1. The first set contains all of the regional physics that need to be simulated to create a useful Location File.
2. The other set contains available data and information about the Location File region from sources outside the model.

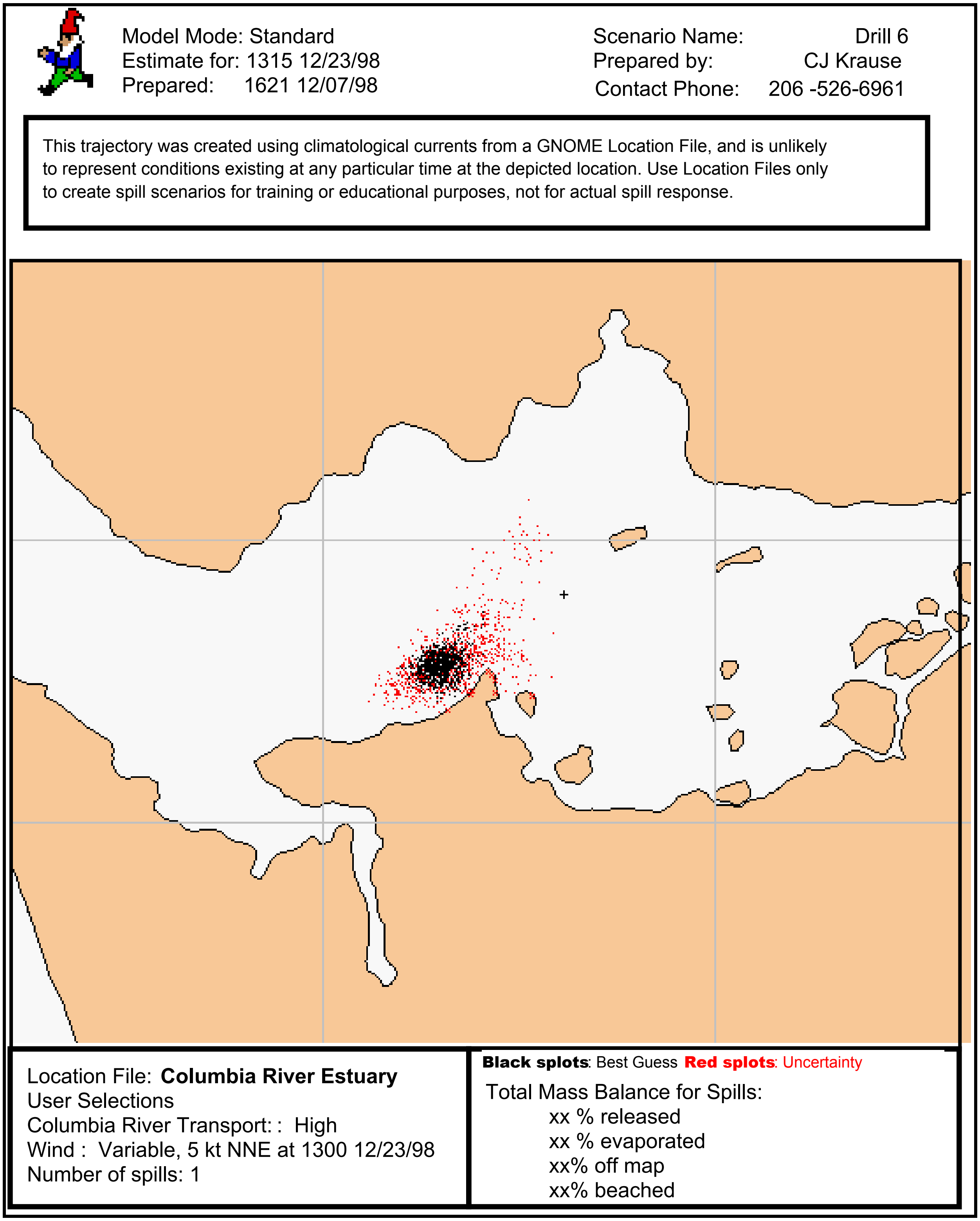

Figure 1. Example of GNOME trajectory product.

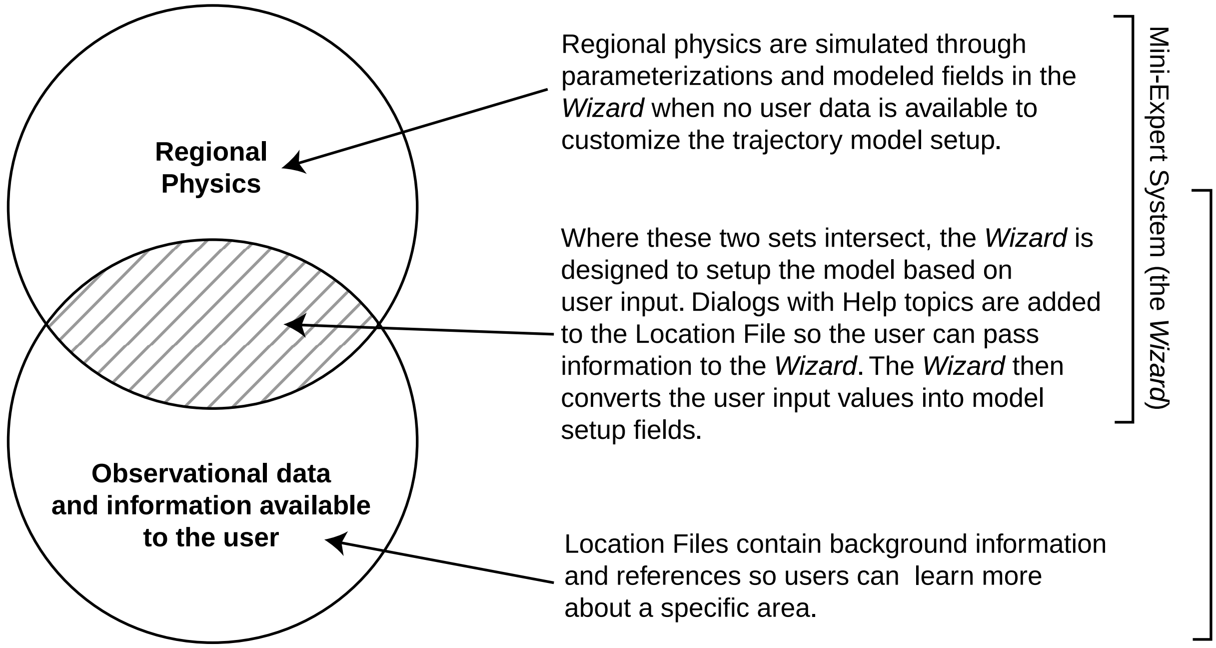

Figure 2. The first step in the design process for GNOME Location Files is to define the overlap between regional physics and observational data. This determines what physics need to be parameterized and what physics the user can set. All of the physics and user interactions are designed into the Mini-Expert System (the Wizard). Background information and references are then added to create a Location File.

The intersection of these sets determines the design of the Location File, from the length and time scales to be simulated to the types of dialogs and support (written materials) with which users will interact.

Every Location File contains at least two dialog boxes with questions for the user:

1. Model settings for date, time, length of model run
2. Wind for wind temporal variability (constant or variable) and values (speed and direction)

Dialog boxes are developed from the intersection of the available data and the regional physics to be simulated. Dialog boxes are used to tie together predictive algorithms to available user data. Highly predictable physics, such as tidal currents, are simulated in the model with the date and time as the only user input; the necessary data files for calculating the tidal currents and instructions are stored within the Location File. During Location File design, physical processes of a particular area are examined to determine what information is available to the users to help them calibrate the model. If users have information publicly available to help set the value for a particular portion of the physics, then a dialog box, references, and instructions are included in the Wizard, as well as the necessary algorithm and data files. If no information is available to the user, then that portion of the physics must be parameterized without user input, or with limited user input choices. For example, the Columbia River flow rate affects the circulation and hence any spill trajectories in the Columbia River. The dialog box for setting the Columbia River flow rate is shown in Figure 3. Users are asked to either select a climatological value for river flow (high, medium, low flow rate) or to find the relevant inputs from other sources to allow GNOME to calculate the Columbia River flow through the estuary. The Help topic connected to the button Finding Flow Data contains references, Internet sites, and instructions to help users find and enter the particular flow conditions they desire. In this case, the Wizard utilizes Jay's (1984) parameterization of flow rate to convert the user's input flow values into scaling coefficients for the current pattern that represent the river flow in the Location File.

Other examples of how the user interacts with the model physics through the Wizard dialog boxes include:

- Setting the offshore current relevant to *buoy data* for Galveston Bay from TABS (Texas Automated Buoy System)
- Choosing a circulation pattern for the Santa Barbara Channel based on *winds data* from the National Data Buoy Center (NDBC) buoy and *current data* from the 5-m Vector Measuring Current Meter (VMCM)

All dialog boxes in GNOME contain a button for a Help topic that leads the user through the process of obtaining and, if necessary, interpreting data to answer the question in the dialog box. Sometimes available data are not sufficient to select a single answer from the choices given; in those cases, the Wizard information suggests which options to try to cover the possibilities.

Location Files always contain a list of references—both printed and electronic—for background information, studies used in developing the Location File, and real-time Internet sites for obtaining data. Each Location File also comes with a User's Guide and Example Problems file to acquaint the user with the area and the structure of the Location File.

GNOME with the Location Files is best used for intuition-building and scenario development. For example, a user wanting to know how the river flow or tidal current phase would affect a spill trajectory in a specific area could run GNOME with that area's Location File and set up a spill scenario. The user could run GNOME with one setting for time of spill (changing the time of the spill changes the tidal phase) or river flow-rate, and then rerun the scenario by changing only the parameter of most interest. GNOME is designed for ease of adjustment to changing conditions.

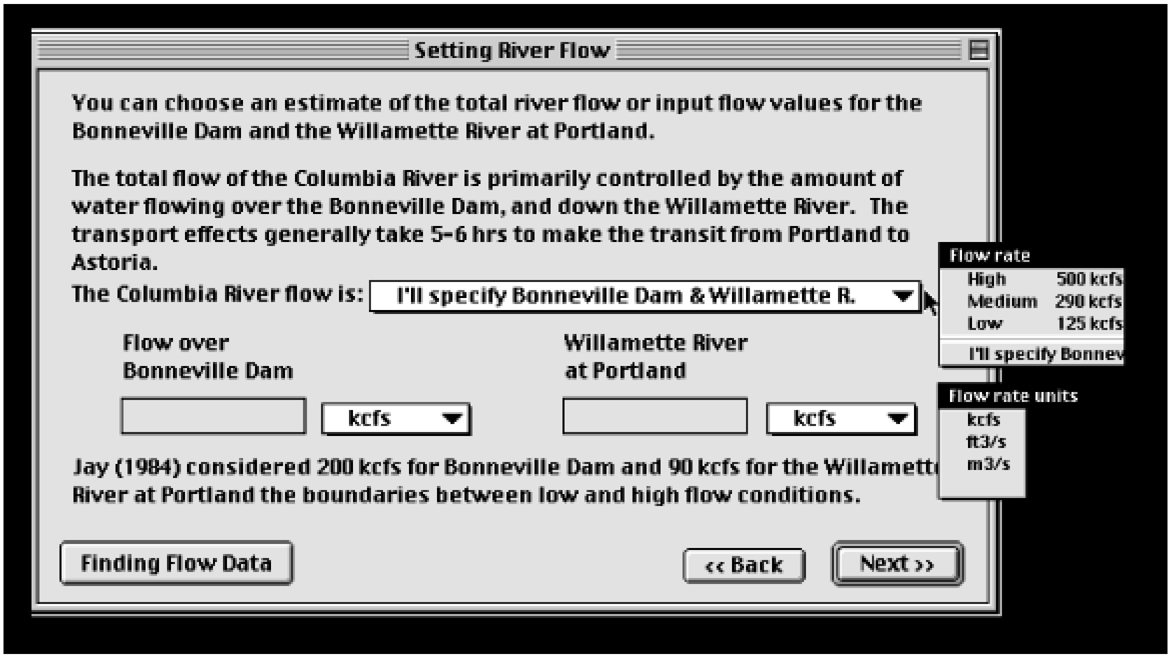

Figure 3. GNOME dialog box illustrating user selections for setting the river flow rate. The user can select statistical high, medium, or low flow rates, or they can find real-time flow values for the main tributaries and the Wizard will calculate the transport rate.

Users also can set up drills or tabletop exercises in GNOME by running the already-planned scenario and then making small, iterative adjustments to the winds, timing of the spill, or other local physics. This exercise of figuring out how to adjust the model to achieve the desired results builds the user's intuitive knowledge about how different forces affect trajectories and how small changes (e.g., shifts in wind speed or direction) can sometimes dramatically influence a trajectory. Trajectory modelers use this type of physical intuition when adjusting the model and when making spill *hindcast*s to match overflight observations.

As mentioned earlier, Location Files are not appropriate for use during spill response. Location Files deal with climatological conditions, while the real ocean on a given day can be highly variable. An expert should do trajectory forecasting, and HAZMAT is available 24 hours a day to provide expertise during spill response throughout the United States and its territories.

Conclusions

GNOME is a trajectory model for use by people with a wide range of spill experience, from the interested public to experienced trajectory analysts. This user diversity is accomplished through three different user modes within GNOME, and ancillary Location Files aid in setting up a trajectory model for the user's particular region. Location Files are region-specific trajectory models containing all the necessary hydrodynamic data and a Mini-Expert System (Wizard) to help users set up GNOME for their situation. The Wizard queries the user about local conditions—with suggestions on where to find the answers and how to interpret them—and then sets up the model accordingly. Experienced trajectory modelers can use GNOME with their own hydrodynamic models to create custom trajectory models. Development is moving ahead toward extending GNOME's capabilities from 2-D time-dependent currents to 3-D time-dependent currents. GNOME supports the NOAA standard for trajectory output of both the Best Guess and Minimum Regret solutions for the trajectory forecast.

GNOME, its User's Manual for Standard and GIS Output Modes, the Location Files, User's Guides, and Example Problems are all available from the Office of Response and Restoration Web site[4].

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Biography

C. J. Beegle-Krause has been a physical oceanographer with NOAA/HAZMAT for 3 years, previously was employed in oceanography education (primary through undergraduate level) and oceanography consulting. She earned her B.S. at the California Institute of Technology, her M.S. in Physical Oceanography from the University of Alaska-Fairbanks, and her Ph.D. in Physical Oceanography from the University of Washington. Dr. Beegle-Krause's research focus is 3-D modeling of chemical transport in fluids and oil-spill trajectory modeling. She currently serves on the HAZMAT response team (both on- and off-site), is the GNOME project coordinator and primary designer and developer of GNOME Location Files, and conducts training in trajectory modeling.

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[1] Available on-line at *http://response.restoration.noaa.gov*.
[2] Available on-line at *http://response.restoration.noaa.gov/software/gnome/gnome.html*.
[3] A good discussion is available on-line at *http://www.unidata.ucar.edu/cgi-in/mfs/01/packages/netcdf/index.html*.
[4] Available on-line at *http://response.restoration.noaa.gov/software/gnome/gnome.html.*